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Estimating Above-Round Biomass and Carbon Stocks of *Prosopis juliflora* using Allometric Equations in Drylands of Magadi, Kenya

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Abstract: Above-ground biomass and carbon stocks of *Prosopis juliflora* were estimated using allometric equations in floodplains and hillslopes landscapes of the drylands of Magadi in Kajiado, Kenya. Three hundred and twenty Prosopis trees were sampled, out of which one hundred and twenty eight were randomly selected and used for the development of the allometric equations. Basal diameter, diameter at breast height, crown width and tree heights were measured; and their fresh weights taken for the development of Prosopis biomass prediction models. Cubic and power models yielded better results than linear models in biomass prediction with basal diameter being more reliable than diameter at breast height, crown width and height. Cubic curvilinear and power models for biomass prediction returned the better R^2 values (0.82 and 0.98) for single and multistemmed Prosopis trees respectively. Validation of models revealed significant correlation between predicted and measured tree biomass, suggesting effectiveness of the models in biomass predictions. The dense and managed plots in the hilllslopes had the highest Prosopis biomass (44.13 tons ha^{-1}) followed by dense and unmanaged plots (43.68 tons ha^{-1}). The dense and unmanaged plots of the floodplains had lower estimates (34.15 tons ha^{-1}) followed by dense and managed (28.01 tons ha^{-1}). The moderately and sparsely dense plots in both landscapes recorded lower biomass (18.75 and 3.47 tons ha^{-1} in hillslopes and 12.72 and 5.09 tons ha^{-1} in floodplains). The effects of management were not significant in both the hillslopes and floodplains. There was growth in the Prosopis biomass trends in the dense and unmanaged Prosopis clusters but there was no change of in the moderately dense and the sparsely dense clusters during the period of study. There were insignificant differences in biomass productivity between the dense managed

Prosopis plots and the dense unmanaged prosopis plots in the hillslope landscape, although, the biomass in the dense managed plots were consistently higher than in the unmanaged. In the floodplains landscape, the biomass for the dense managed Prosopis plots was consistently lower than the dense unmanaged Prosopis plots but the differences were also insignificant. Further studies were recommended with longer time frames of observations to assess the effect of management on biomass production.

INTRODUCTION

Introduced in Kenya for land rehabilitation during the 1970 and 1980s (Choge and Pasiecznik, 2006; Wahome *et al*., 2008), *Prosopis juliflora* has become invasive through its superior aridity adaptive qualities and ubiquitous seed production. It is a threat to productivity of the drylands due to its invasive nature but on the flip side it offers opportunity for the dryland communities to benefit from carbon credit trade but there are barriers of initiating carbon credit schemes in the drylands, chief of them is methodological constraints. It is estimated that 2% of Kenya's landmass is now covered by prosopis whose pod production potential has been estimated at about 60.000 tons per year (Choge and Pasiecznik, 2006).

Prosopis trees account for a significant amount of plant biomass and consequently, sequestered carbon worldwide. However, most of the previous studies on plant biomass estimation have focused on species from humid areas with little recognition of those adapted to dry environments. Tree species in arid and semi-arid zones are not currently considered when calculating carbon balances. There is yet an undiscovered value of Prosopis in the emerging global market for 'carbon credits'.

Plant biomass is the total amount of live material in a plant that includes water and other chemicals. Carbon is an equivalent of charcoal from a tree when all the water is evaporated and it has been estimated at 50% of plant biomass (Losi *et al*., 2003; IPCC, 2003). Modest improvements in Prosopis silvicutural management can raise biomass by as much as 0.5 tons C/ha/year in the drylands (Reid *et al*., 2004; Galvin *et al*., 2004). This is important since in the moisture stressed and degraded soils of the Kenya's rangelands, *P. juliflora* contributes an increasingly significant proportion of sequestered carbon (Steinfeld *et al*., 2006) with the potential of offering pastoral communities an opportunity to benefit from Prosopis based carbon credit trade-off schemes.

Biomass has been estimated by ground physical measurements, otherwise known as allometric equations (Roy and Ravan, 1996) which are unique to particular tree species (Chave *et al*., 2004). In the drylands, the methods are hampered in part by inadequate and underdeveloped methods of accounting for carbon stocks (Galvin *et al*., 2004) and highly variable canopy cover among sites and species (El Fadl *et al*., 1989; Geesing *et al*., 2004).

The few allometric equations developed for *Prosopis* biomass estimation (Singh and Singh, 2011) cannot be easily replicated and are limited in their application and scaling-up potential. There is need to build consensus around the more reliable parameter to use between Basal Diameter (BD) and Diameter at Breast Height (DBH) and how to handle the multistemmed nature of Prosopis trees in estimating Prosopis biomass and carbon stocks (Redondo-Brenes, 2007). This will contribute to the increased accuracy of the estimated above ground biomass (Chave *et al*., 2004). This paper reports on the determination of an equation that enhances the accuracy of estimating *P. juliflora* AGB production and carbon stocks to model potential for trading in carbon credits.

MATERIALS AND METHODS

The study area: The study was conducted in Olkiramatian location of Magadi division-Kajiado County. The area is located in south west of Kenya, bordering Tanzania to the south and Narok County to the west. It is situated at altitude of 600m within lat/long. 140°'S, 36°E, 2°S, 36°15'E (Fig. 1), under the inner lowland and lower midland agro-ecological zones. It has a bimodal rainfall pattern with a an annual total of 460 mm and a mean of 50 mm, mean temperatures of 32°C. The soil texture is very clay, clay and loam with occasional sand. The clay types are montmorillonitic, kaolinitic and interstratified clay. The landforms are composed of plains, plateaus, low gradient foot slopes, medium gradient hills and occasional high gradient hills. The slopes range from flat and wet slopes, gently undulating, rolling and steep slopes. The vegetation is sparse, open bushland with increasing presence of Prosopis.

Prosopis spread in Magadi division is mainly found in Olkiramatian location and the study is mainly concentrated in Ngurumani, Olchorro Olepo and Entasopia sublocations. These are the original sites where Prosopis was originally introduced. There are well established Prosopis stands with adequate dense, moderate and sparse *Prosopis clusters*. Floodplains and hillslopes landscapes are well represented in these areas.

The study sites were located in the Ngurumani hillslopes in Ngurumani and Entasopia sublocations and

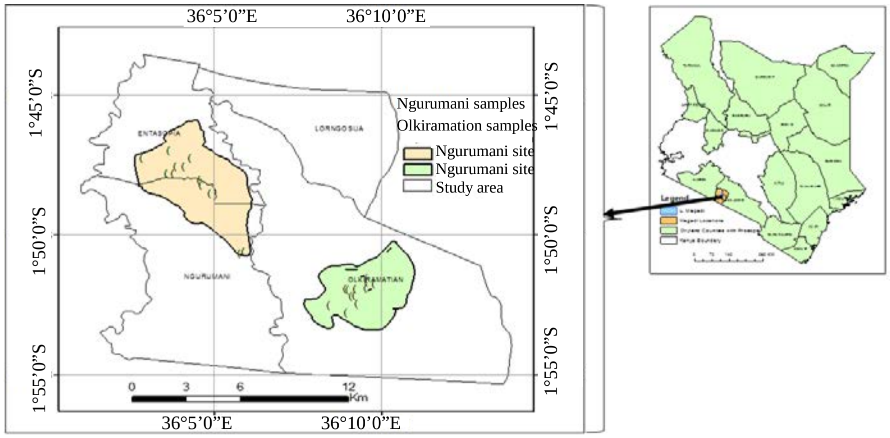

Fig. 1: Study area in Magadi of Kajiado county, Kenya

Olkiramatian floodplains in Olkiramatian sublocation (Fig. 1). These are the areas invaded by Prosopis with well-established Prosopis stands in the dense, moderate and sparse clusters.

The Olkiramatian floodplains receive 400 mm of rainfall annually, average temperatures of 35°C and vegetation cover of mainly shrubs, Prosopis and bare land. The Ngurumani hillslopes receives 600 mm of rainfall annually with mean temperatures of 28°C and vegetation dominated by bushland, Prosopis and irrigated crop fields.

Sampling design and delineating the Prosopis density sites: Two *Prosopis landscapes* of hillslopes and floodplains were selected purposefully. Within each landscape, three sites containing sparse density (<30% Prosopis cover), moderate Prosopis density of 50-70% cover and high Prosopis density (dense) of greater than 70% Prosopis cover were identified purposefully. The Prosopis density clusters were delineated using satellite images MODIS (250 m), land use and land cover and validated using GPS data. These datasets were also used for ground truthing delineating Prosopis infested areas.

Each site had four plots of 30×30 m randomly selected and fenced off to prevent interference from livestock, wildlife and humans. The four plots in each site had biomass estimation variables (basal diameter, breast height diameter, crown width, tree hieght) measured in the natural state. In the dense Prosopis sites (>70% Prosopis), other four plots were selected randomly and management practices applied (pruning and 5 m spacing between the Prosopis trees). The purpose of management was to reduce crowding, competition and increase production. The managed plots were only located in the high Prosopis density clusters (dense) due to fact that in the other sites of sparse and moderately dense areas, there was no need of management due to the occurrence of naturally spaced Prosopis stands. The total number of plots in the whole study area (in the 2 landscapes) was (2*(4+4+4+4)) = 32.

Using participatory resource mapping approach involving the local communities, the study sites were stratified into hillslopes and floodplains which were further categorized depending on the density of Prosopis stands into sparse, moderate and dense Prosopis sites. The mapping was done on the area topomap sheet with a scale of 1: 50,000. The identified Prosopis strata and sites was then be digitised in GIS Software (ArcGIS) to create a GIS shapefiles of Prosopis density strata and sties.

In order to randomly select the sampling plots for data collection, the digitized Prosopis density shapefiles were then partitioned into 30 m^2 grids and each grid assigned a unique number. MS Excel software was used to generate 4 random numbers from the unique numbers in each of the four Prosopis density sites. The random numbers generated were used as the identifiers of the randomly sampled plots. The selected plots were then identified on the ground using GPS and fenced off to prevent interference from livestock, wildlife and humans and all the field observations taken on them.

In the dense Prosopis sites, two 30 m^2 plots were randomly selected and demarcated side by side. One of the two plots had management practices applied (pruning and spacing) and the other plot was left in the natural state as a control to enable comparison of the measured attributes.

Selection and management of Prosopis plots: Thirty two plots were randomly selected in each of the two purposefully identified Prosopis landscapes of Ngurumani hillslopes and Olkiramatian plains. Four plots were managed and twenty eight were left in the natural state (unmanaged). The managed plots were placed adjacent to the unmanaged plots in the dense sites anddemarcated as such. The management involved pruning (2-3 stems per plant) and thinning to space (5 m apart) of the naturally occurring trees. Any vegetation undergrowth and re-growth was regularly removed in the managed plots.

The *Prosopis plants* (above 3 m in height and producing pods) in each observation plot were identified and counted. The 10 Prosopis shrubs and trees in each plot were randomly selected (sampled) and basal diameter (m), breast height diameter (m), tree height (m) and crown diameter (m) measurements taken once every month for both managed and unmanaged plots.

Field data collection in the two *Prosopis landscapes* (Ngurumani hillslopes and Olkiramatian floodplains) was done once a month for ten months in each of the 32 plots. In the managed plots, stems were thinned and pruned (2-3 stems per stump) and spaced at 5 m. Measurements of base diameter and Diameter at Breast Height (DBH), tree height and crown diameter, all in meters (m) were taken in the managed and unmanaged plots.

Development of allometric equation using ground truthed data: A total of One hundred and twenty eight Prosopis trees were randomly selected (four each from the ten sample trees in the 32 plots). The measurements of Basal Diameter (BD), Breast Height Diameter (DBH), tree height and crown diameter variables were taken in the managed and unmanaged plots for the development of the allometric equations.

All the 128 sampled trees were then cut down the actual weights (fresh weights) determined with a spring balance. To determine the whole tree weight, trees were cut into small sizes immediately after felling. Tree segments of weights that could be easily lifted were fastened together with a sisal twine and weighed with a spring balance until the entire tree materials were exhausted. Weights were then recorded separately for each tree.

SPSS software was used for the analysis. Exploratory analysis (variable and model evaluation) was done to find out the appropriate variables and models for estimating biomass. Stepwise regression analysis was carried out to compare diameter (DB and DBH) based biomass estimates with height and crown width based biomass estimates in Olkiramatian floodplains and Ngurumani hillslopes. Linear, Quadratic, cubic and Power regression models were applied to the one, two and three stemmed Prosopis basal diameter variables. Scatter plots were developed and coefficient of determination (R^2) evaluated for the relationships between the actual and estimated biomass.

Non-linear regression equations for estimating Prosopis biomass from previous studies (Eq.1-3) were applied using FW and BD as the dependent and independent variables (Cienciala *et al*., 2013; Chave *et al*., 2005; Dabasso *et al*., 2014; Henry *et al*., 2011):

$$\mathrm{Ln}(\mathrm{FW}(\mathrm{kg})) = 0.292\mathrm{DB}+0.59 \quad (1)$$

$$\mathrm{FW} = \lambda * \exp\begin{pmatrix} \mathrm{p0}+\mathrm{p1}*\mathrm{In}(\mathrm{EDBH})+\mathrm{p2}*\mathrm{In}(\mathrm{H})+ \\ \mathrm{p3}*\mathrm{In}(\mathrm{SN})+\mathrm{p4}*\mathrm{In}(\mathrm{CW}) \end{pmatrix} \quad (2)$$

$$\mathrm{FW} = 0.1975\times 1.1859\mathrm{DBH} \quad (3)$$

Where:
FW = Estimated biomass
BD = Basal diameter
λ = Correction factor
EDBH = Tree equivalent diameter at breast height
H = Tree height
SN = No. of stems with diameter larger than 5 cm
CW = Crown width and
p0-p4 = Fitted parameters
x = Ratio of BD and DBH

These models (Eq. 1-3) either overestimated or underestimated the predicted biomass and did not show any correlations between the actual field weights measurements and the estimated biomass. Using the same principles, other models were developed which were found to be working for this study.

The field Prosopis data variables from the 128 sampled trees was also used to develop allometric equations for estimating Prosopis a Above Ground Biomass (AGB) collected in Olkiramatian and Ngurumani for a period of 10 months. The data was divided into one stem, two stems and three stems Prosopis trees at the base (BD). Linear, quadratic, cubic and power regression equations, using Fresh Weight (FW) in kg as the dependent variable and BD (cm) as the independent variable were developed for the one, two and three stemmed Prosopis trees. The following models were used:

$$Y = \beta_0+(\beta_1 * t) \quad (4)$$

$$Y = \beta_0+(\beta_1 * t)+(\beta_2 * t^2) \quad (5)$$

$$Y = \beta_0+(\beta_1 * t)+(\beta_2 * t^2)+(\beta_3 * t^3) \quad (6)$$

$$Y = \beta_0 * (t^{\beta 1}) \text{ or } \mathrm{In}(Y) = \mathrm{In}(\beta_0)+(\beta_1 * \mathrm{In}(t)) \quad (8)$$

Where:

Y	=	The estimated biomass (kg)
t	=	The basal diameter measured at a height of 30 cm from the ground
β_0, β_1, ..., ßn	=	Coefficients

To estimate Prosopis biomass and carbon stocks in Olkiramatian and Ngurumani landscapes, the above biomass estimation models were applied. The field Prosopis data was divided according to the sites (Olkiramatian plains and Ngurumani hillslopes). The data was further subdivided into one, two and three stemmed Prosopis biomass samples and the developed basal diameter and fresh weights relationship models applied to estimate biomass. Aggregations of biomass and carbon stocks (tons/ha) were done and averages calculated for each landscape type.

Scatter plots were developed for the single, two and three stemmed Prosopis trees to establish relationships between actual and estimated biomass (weights). The actual (measured weights) were plotted as the independent variables against the estimated weights as the dependent variables to determine the relationship of the measured and estimated weights. The R^2s were determined and the best models based on R^2 were selected for the single, two and three stemmed Prosopis trees based on the relationships between actual and estimated biomass (weights).

The Least Significant Difference (LSD) was used to separate the means. To evaluate the effect of landscape type and season on the carbon level of various carbon pools, a General Linear Model (GLM) was used and significant difference accepted at 5% level of probability error (Dabasso *et al*., 2014; Steel and Torrie, 1980; Mead and Curnow, 1990). Split-plot ANOVA were used to test for differences between the repeated measurements of biomass production in the managed and unmanaged plots.

RESULTS AND DISCUSSION

The cubic models (Eq. 6) with R^2 = 0.98 for the two stemmed trees and power models (Eq. 7) with R^2 = 0.8; R^2 = 0.73 for the one and three stemmed trees, respectively, showed significant relationships between the measured and the predicted biomass and were used in estimating Prosopis biomass in this study:

$$Y = \beta_0 + (\beta_1 * t) + (\beta_2 * t^2) + (\beta_3 * t^3) \quad (8)$$

$$Y = \beta_0 * (t^{\beta 1}) \text{ or } In(Y) = In(\beta_0) + (\beta_1 * In(t) \quad (9)$$

The results of the linear, quadratic, cubic and power regression models (Table 1-3) for the one stemmed, two stemmed and three stemmed basal diameter Prosopis trees showed that the power regression model was a better estimator (R^2 = 0.82) of the biomass in the one stemmed Prosopis trees (Table 1). The results also showed that the cubic regression model was a better estimator (R^2 = 0.98) of the biomass in the two stemmed Prosopis trees (Table 2). The results also showed that the power regression model was a better estimator (R^2 = 0.73) of the biomass in the three stemmed Prosopis trees (Table 3).

Actual and estimated biomass relationships of the Prosopis biomass models: Scatterplot for the single stemmed Prosopis trees (Fig. 1-3) showed very strong and positive relationships between actual and estimated biomass (R^2 = 0.8). Scatterplot for the two stemmed Prosopis trees (Fig. 2) showed the strongest relationships between actual and estimated biomass (R^2 = 0.98) and the scatterplot for the three stemmed Prosopis trees (Fig. 3) showed reasonable relationships between actual and estimated biomass (R^2 = 0.73).

Estimation of Prosopis biomass and carbon stocks: The Prosopis biomass estimates in the two landscapes of Ngurumani and Olkiramatian and in the four different density classes of dense managed, dense unmanaged, moderately dense and sparsely were compared. Ngurumani hillslopes landscape with higher rainfall amounts and lower temperatures had the highest Prosopis biomass (44.13 tons ha^{-1}) in the dense managed category (Table 4). This was followed by dense unmanaged category (43.68 tons ha^{-1}) also in the high rainfall and low temperature Ngurumani. The lowland plains of Olkiramatian had the third and fourth highest Prosopis biomass estimates in the dense unmanaged (34.15 tons ha^{-1}) followed by dense managed category (28.01 tons ha^{-1}) of the Olkiramatian plains. The moderately and sparsely dense categories in both landscapes recorded the lowest Prosopis biomass (18.75 and 3.47 tons ha^{-1} in Ngurumani and 12.72 and 5.09 tons ha^{-1} in Olkiramatian (Table 4).

Carbon is an equivalent of charcoal from a tree when all the water is evaporated and it has been estimated at 50% of plant biomass (Hoen and Solberg, 1994; Losi *et al*., 2003; IPCC, 2003). Carbon stocks were estimated at 50% of the biomass (Dabasso *et al*., 2014; Henry *et al*., 2011) for the sparse, moderately dense and managed and unmanaged dense Prosopis plots in Ngurumani and Olkiramatian landscapes (Table 4).

Although, the biomass values for the dense managed Prosopis plots were higher than the dense unmanaged Prosopis plots, the effects of management (spacing and pruning) were not noted in the Ngurumani landscape as the differences were insignificant (Table 4). However, the biomass values for the dense managed Prosopis plots were lower than the dense unmanaged Prosopis plots in the Olkiramatian plots and again there was no effect of

Table 1: Regression results of one stemmed prosopis basal diameter (cm)

			Coefficients		
Regression equation	R^2	Intercept/Constant	b1	b2	b3
Linear	0.76	-43.19	7.75		
Quadratic	0.79	3.30	0.40	0.20	
Cubic	0.79	30.13	-5.92	0.60	-0.01
Power	0.82	0.54	1.69		

Table 2: Regression results of two stemmed prosopis basal diameter (cm)

			Coefficients		
Regression equation	R^2	Intercept/Constant	b1	b2	b3
Linear	0.75	-103.42	20.00		
Quadratic	0.94	90.69	-25.30	2.02	
Cubic	0.98	-76.66	35.95	-4.27	0.18
Power	0.85	0.67	1.92		

Table 3: Regression results of three stemmed prosopis basal diameter (cm)

			Coefficients		
Regression equation	R^2	Intercept/Constant	b1	b2	b3
Linear	0.67	-28.99	9.72		
Quadratic	0.70	-114.36	19.64	-0.20	
Cubic	0.70	-120.97	20.96	-0.27	0.00
Power	0.73	0.94	1.62		

Table 4: Distribution of biomass and carbon stocks in different prosopis densities in Ngurumani and Olkiramatian landscapes

	Biomass and carbon stocks (Average tons ha^{-1})			
	Ngurumani landscape		Olkiramatian landscape	
Parameters	Biomass	Carbon	Biomass	Carbon
Dense managed	44.13^a	22.065	28.01^a	14.005
Dense unmanaged	43.68^a	21.84	34.15^a	17.075
Moderately dense	18.75^b	9.375	12.72^b	6.36
Sparse	3.47^c	1.735	5.09^c	2.545

Means with different letter superscripts down each column are significantly different (*p<0.05)

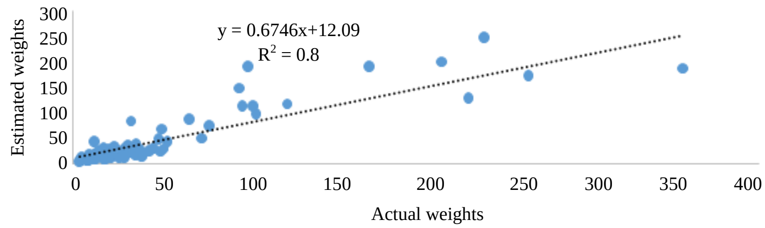

Fig. 2: Single stem Prosopis basal diameter (actual vs. estimated weights)

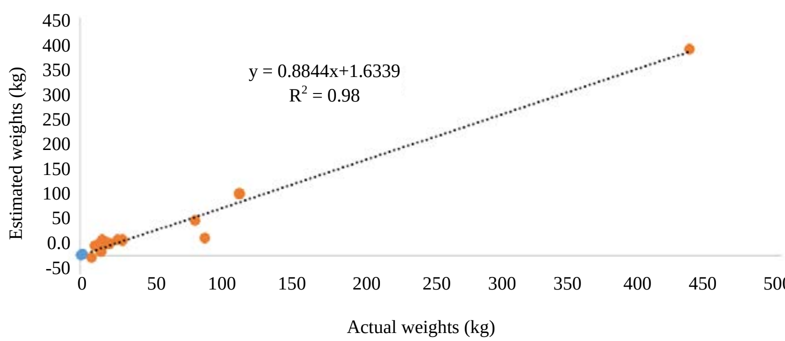

Fig. 3: Two stem Prosopis basal diameter (actual vs. estimated weights)

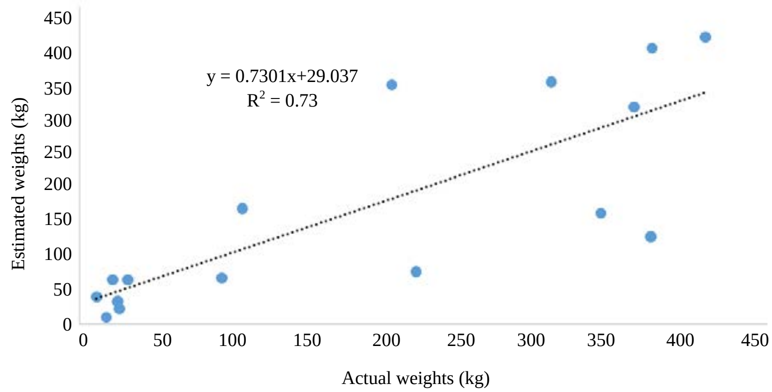

Fig. 4: Three stem Prosopis basal diameter (actual vs. estimated weights)

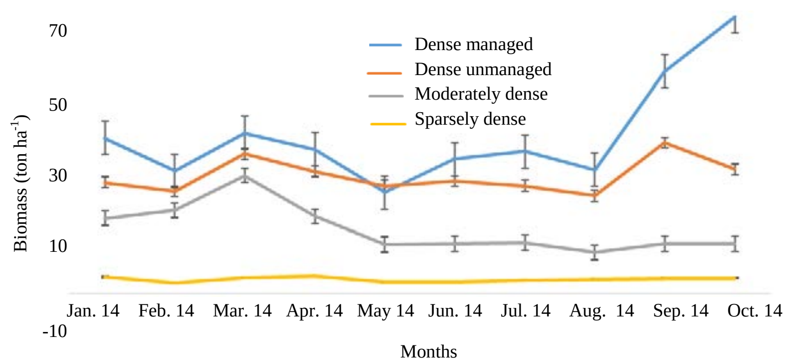

Fig. 5: Prosopis biomass trends in Ngurumani landscape

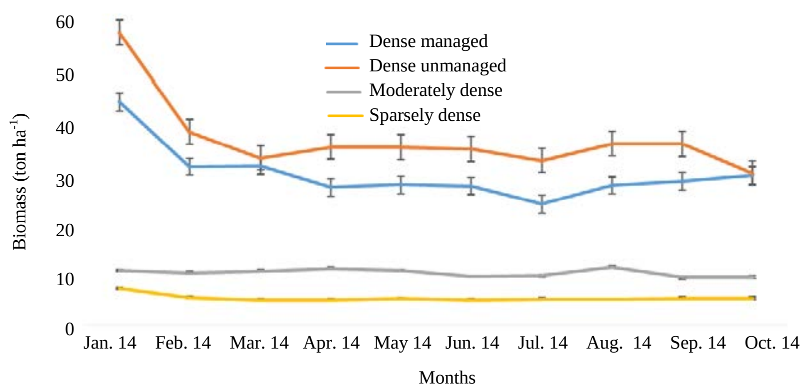

Fig. 6: Prosopis biomass trends Olkiramatian landscape

management in Olkiramatian landscape as the differences were insignificant (Table 4). A longer time of observations might be needed for the effect of management to the realized in biomass production.

The Prosopis biomass growth in the moderately and the sparsely dense clusters were significantly differently in Ngurumani but not in the Olkiramatian landscape. Possible reasons included greater competition for the available growth resources (water and light) with other vegetation types including other Prosopis plants outside the sample, leading to depressed and differentiated growth.

Time series and trends analysis: Prosopis biomass time series trends in Olkiramatian and Ngurumani landscapes were plotted in charts with time (months) as X axis and Prosopis biomass as Y axis. The four lines (trends) for dense (managed and unmanaged), moderate and sparse densities were drawn and fitted with error bars (Fig. 4-6). The Prosopis biomass trends were developed for the dense and managed, dense and unmanaged, the moderately dense and the sparsely dense Prosopis clusters (Fig. 4 and 5). Although, the biomass values for the dense managed Prosopis plots were consistently higher than the dense unmanaged Prosopis plots, the effects of management (spacing and pruning) were not noted in the Ngurumani landscape as the differences were insignificant (Fig. 4). However, the biomass values for the dense managed Prosopis plots were consistently lower than the dense unmanaged Prosopis plots in the Olkiramatian plots but again there was no effect of management in Olkiramatian landscape as the differences were insignificant (Fig. 5). Possible reasons for the observed trends included less competition for plant growth resources (water and light) in the Ngurumani dense clusters as compared to the Olkiramatian floodplains with higher water stress. There was little effect of management on Prosopis productivity in both landscapes in the dense category of plots. A longer time frame for this type of experiment might be required to realize it.

The Prosopis biomass growth in the moderately and the sparsely dense clusters were significantly differently in Ngurumani but not in the Olkiramatian landscape over the study period (January-October, 2014). Possible reasons included greater competition for the available growth resources (water and light) with other vegetation types including other Prosopis plants outside the sample.

One source of error in estimating carbon stocks in Prosopis forests is the lack of specific models for converting tree measurements to aboveground biomass (AGB) estimates. Log transformed (Duff *et al*., 1994; Padron and Navarro, 2004; Alvarez *et al*., 2011) and untransformed (Maghembe *et al*., 1983; Padron and Navarro, 2004) basal diameters have been used for Prosopis biomass prediction depending on the species and nature of the stand studied. Evaluation of model development using transformed and untransformed data could not justify data transformation as reliable models were obtained with untransformed data (Kariuki *et al*., 2012).

Chave *et al*. (2005) estimated above ground biomass for dry forest stands using a mix of specific gravity, exponential and natural logarithm of the basal diameter in a nonlinear allometric equation. This was an attempt to improve the quality of tropical biomass estimates and bring consensus about the contribution of the tropical forest biome and tropical deforestation to the global carbon cycle.

The use of allometric regression models is an important step in estimating AGB, yet it is seldom directly tested in species specific plant ecosystems. Single stem diameter biomass estimation methods (Kariuki *et al*., 2012; Cienciala *et al*., 2013) were used in estimating Prosopis above ground biomass in previous studies. The two estimation approaches were applied to the field data in this study and the estimates compared with the groundtruthed Prosopis biomass data. The models either over estimated or under estimated the biomass.

The variance of the Prosopis fresh weight biomass and the estimated biomass was too large for application in this study. Kariuki *et al*. (2012) found that power (loglinear) models were stronger than linear models the Prosopis fresh weight biomass. However for multi stemmed trees, only one stem was sampled and uniformity of tree characteristics assumed for the other stems. Cienciala *et al*. (2013) and Dabasso *et al*. (2014) estimated Prosopis biomass from multiple stems at base and at breast height using a model with a correction factor, tree equivalent diameter at breast height and fitted parameters. Power models were stronger than linear models in relating fresh weight to tree diameters, (Kariuki *et al*., 2012). Dabasso *et al*. (2014) and Henry *et al*. (2011) used power allometric equation with a correction factor to estimate biomass fresh weight in Marsabit drylands of Kenya. To estimate dry biomass, the results are multiplied by 60% and the carbon content taken as 50% of the dry biomass weight.

Prosopis juliflora is usually multiple stemmed plant which the previous models did not address significantly. Therefore models were explored for estimating multiple stemmed Prosopis using multiple diameter biomass estimation methods. Curvilinear and power models were found to be promising models for estimating Prosopis biomass in the drylands of Kenya. In areas with substantial water resources in the drylands, management of the Prosopis clusters improves the rate of growth (productivity) as opposed to the drier areas.

CONCLUSION

This study found that curvilinear and power models improved the estimation of the above ground Prosopis biomass in the drylands. There were insignificant differences in biomass productivity between the dense managed Prosopis plots and the dense unmanaged Prosopis plots in the hill slope landscape, although, the biomass in the dense managed plots were consistently higher than the unmanaged. In the flood plains landscape, however, the biomass for the dense managed Prosopis plots were consistently lower than the dense unmanaged Prosopis plots but the differences were also insignificant. Further studies were recommended with longer time frames of observations to assess the effect of management on biomass production. More studies are also recommended for the development of allometric equations of estimating biomass of Prosopis plants whose height is <2 m in height. Also, the economics of Prosopis carbon stocks as Prosopis based carbon trade need further studies.

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